EUROPEAN ASSOCIATION OF CARDIOVASCULAR IMAGING
A Registered Branch of the ESC

EACVI CORE SYLLABUS

for Cardiovascular Magnetic Resonance in congenital and paediatric heart disease

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The European CMR exam syllabus will be reviewed and amended on a regular basis. The European CMR exam syllabus provides detailed information about what the candidate is expected to be familiar with and can thus guide in the preparation for the exam. The European CMR exam syllabus is not exhaustive and the candidate should be aware that questions may be asked in the European CMR exam that do not map to the current version of the syllabus.

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CARDIOVASCULAR MAGNETIC RESONANCE IN CONGENITAL AND PAEDIATRIC HEART DISEASE

1. GENERAL CONCEPTS, SAFETY, DEVICES, PHYSICS, CMR METHODOLOGY

1.1. General concepts

1/ The role of CMR in congenital and acquired heart disease of childhood, and adult congenital heart disease.

2/ Indications for CMR

3/ The position of CMR with respect to complementary technologies; XR; Echo; CT; NM

1.2. MR safety

1/ Main magnet

2/ Radio frequency transmit/receive systems

3/ Magnetic field gradients systems

4/ Static field biological effects Safety zones for MRI facility, I-IV (USA)

5/ Radio frequency field biological effects

- Sequence-related patient heating
- Factors affecting SAR & how to reduce it

6/ Gradient fields biological effects

- Acoustic noise during MRI scanning
- Peripheral nerve stimulation

7/ Precautions prior and during an MRI examination

8/ Pregnancy

9/ Emergency procedures

10/ Contrast agents: families of contrast agents, effect on relaxation times, contraindications (renal failure-NSF, allergy,

pregnancy) and main applications

1.3. Device Safety

1/ MRI device safety classifications

2/ Passive implants and devices: valve repairs, stents, coils, aneurysm clips and other implants and devices

3/ Active devices: implantable loop recorders, implantable cardioverter defibrillator (ICD), pacemakers, abandoned leads

- Safe, conditional and unsafe devices
- Precautions pre and post scans
- Safety at 1.5T and 3T

1.4. Physics

1/ Basic magnetic resonance physics

- Magnetic properties of hydrogen nuclei: Precession, Resonance, Larmor frequency, Excitation
- Relaxation mechanisms: T1 and T2 relaxation times
- Tissue properties: T1, T2 and T2*
- Different field strengths (1.5T and 3T)

2/ Signal spatial encoding

- Scanner parameters: B0 field strength, gradient strength Radio frequency system: Transmit and receive coils, phased array coils, surface coils, RF pulses, need for Faraday cage
- Magnetic field gradients: relationship between spatial encoding and spatial frequency
- 2D signal encoding: Slice selection, Phase and frequency encodings

- Interpreting spatial encoding in MRI: k-space properties and Fourier transform
- Relationships between contrast, spatial resolution, matrix size, acquisition time, field of view, receiver bandwidth and k-space
- 3D spatial encoding

3/ Basic pulse sequences

- Basic excitation pulses: 90° pulse, 180° refocusing and inversion pulses (selective vs non-selective)
- Basic gradient and spin echoes
- Signal-to-noise ratio (SNR) and parameters affecting it (e.g. voxel size, signal averages, receiver BW, B0, partial k-space acquisition, 2-D vs 3-D)
- MRI tissue contrasts: Relation between TR, TE, flip angle and T1- weighting, T2- weighting, proton density-weighting imaging
- Prepulses and their effect on tissue contrast: Inversion Recovery, STIR, fat suppression, T2-preparation
- Basic pulse sequence diagrams

4/ Advanced and fast pulse sequences

- Fast spin echo sequences
- Spoiled gradient echo, balanced steady state free precession (SSFP)
- Echo planar imaging (EPI) and non Cartesian imaging
- Sequence acronyms: generic sequence names and vendor specific names

5/ Parallel imaging

- Radio frequency system for parallel imaging: Phased array coils
- Benefits and drawbacks of parallel imaging: scan time, SNR, noise level
- Image acquisition and reconstruction methods: image domain, frequency domain, spatio-temporal domain
- Main applications

6/ MR Angiography (MRA) flow imaging

- Non-contrast magnetic resonance angiography methods: Time-of-flight MRA, Phase-contrast MRA
- Contrast-enhanced MRA techniques using contrast agents

7/ Cardiac MRI applications

- Cardiac triggering and sequence synchronization, segmented acquisitions
- Respiratory compensation: breath-holding, respiratory navigators, respiratory gating
- Bright blood and dark blood sequences
- Sequences for cardiac morphology, function, tagging and perfusion imaging: type of sequences, optimisation of image quality and scan times
- Sequences for myocardial delayed enhancement MRI: sequence and image quality optimization
- Coronary/bypass graft MRA, Phase contrast velocity mapping

8/ Image quality and artefacts

- Factors influencing the signal-to-noise ratio and their interdependence
- Trade-off between scan time, signal-to-noise ration and spatial resolution
- MRI artefacts, their sources, effects on the image quality and how to reduce them
- Physiological motion: origin of artefacts and remedies (ghosting)
- Imaging of sedated patients and patients with arrhythmias
- Parallel imaging: aliasing, noise amplification
- Magnetic susceptibility and metal artefacts
- Fat-water chemical shift
- Truncation, Gibbs artefacts
- Equipment artefacts
- Shimming

1.5. CMR Methodology

1/ Cardiac function

- Image planning - Short vs Long axis
- Segmentation - Inclusion or exclusion of RV trabeculations
- Regional wall motion abnormalities

2/ Blood flow

- Sequences - free breathing vs breath hold
- Image planning - associated errors
- Sources of error

3/ Anatomical assessment

- Type of sequences (3D)
- Type of sequences (2D)

4/ Tissue characterisation

- Non-contrast techniques
- Contrast-enhanced techniques
- Early gadolinium enhancement
- Late gadolinium enhancement

5/ CMR stress imaging

- Myocardial perfusion imaging
- Dobutamine stress CMR

2. CONGENITAL HEART DISEASE ANATOMY AND PHYSIOLOGY

2.1. Anatomy

1/ Thoracic anatomy including cardiac; vascular; pericardium; lungs; pleura; mediastinal structures; thoracic cage; spine. Appearance of normal anatomical variants.

2/ Sequential segmental approach to describing congenital cardiovascular patterns of disease

- Atrial situs and situs abnormalities; right and left isomerism; situs inversus and situs ambiguous
- Systemic venous return and anomalies
- Pulmonary venous return and anomalies
- Atrial anatomy and defining features of the atria
- Interatrial septum anatomy

- Atrio-ventricular connections; concordance; discordance; double inlet; absence; straddling; criss-cross
- Anatomy of the AV valves
- Ventricular anatomy morphology of the left and right ventricles; AHA/ACC 17 segment model nomenclature
- Univentricular anatomy and identification of variants
- Interventricular septal anatomy
- Ventricular-arterial connections; concordance; discordance; single outlet; double outlet
- Anatomy of the pulmonary and aortic valves
- Pulmonary artery and aorta anatomy; relationships of the great vessels
- Coronary arteries anatomy and variants
- Arterial duct

2.2. Shunt lesions

1/ Atrial Septal Defects

- Anatomy of the atrial septum
- Optimal imaging techniques
- Variants - Secundum; Primum; Superior sinus venosus ; Inferior sinus venosus ;also including unroofed coronary sinus
- Quantification of shunt size - relationship between ventricular volumes and great vessel flow
- Assessment of physiological consequences
- Associated lesions
- Assessment of treatment complications

2/ Ventricular Septal Defects

- Anatomy of the ventricular septum
- Optimal imaging techniques
- Variants - Inlet; Apical; Outlet; Malalignment
- Quantification of shunt size - relationship between ventricular volumes and great vessel flow
- Assessment of physiological consequences
- Associated lesions - aortic valve prolapse; double chambered right ventricle
- Assessment of treatment complications

3/ Atrioventricular Septal Defects

- Variants - Complete; Partial
- Optimal imaging techniques
- Quantification of shunt size - relationship between ventricular volumes and great vessel flow
- Assessment of physiological consequences
- Associated lesions
- Assessment of treatment complications

4/ Ductus Arteriosus

- Anatomical variations of position
- Optimal imaging techniques
- Quantification of shunt size - relationship between ventricular volumes and great vessel flow
- Assessment of physiological consequences
- Associated lesions
- Assessment of treatment complications

5/ Partial Anomalous Pulmonary Venous Connection

- Pulmonary venous anatomy
- Optimal imaging techniques
- Variants
- Quantification of shunt size - relationship between ventricular volumes and great vessel flow
- Assessment of physiological consequences
- Associated lesions
- Assessment of treatment complications

6/ Other Shunting Lesions

- Aorto-Pulmonary window
- Disconnected pulmonary artery
- Pulmonary artery from aorta
- Sinus of Valsalva fistula
- Anatomical features
- Quantification of shunt size - relationship between ventricular volumes and great vessel flow
- Assessment of physiological consequences
- Associated lesions
- Assessment of treatment complications

2.3. Cyanotic Congenital Heart Disease

1/ Tetralogy of Fallot

- Anatomy of repaired and unrepaired Tetralogy of Fallot
- Optimal imaging techniques
- Assessment of physiological consequences

- Relationship of shunting in unrepaired Tetralogy of Fallot to the type of anatomy
- Associated lesions
- Pre-intervention (surgical/ interventional cardiology) assessment
- Assessment of treatment complications

2/ Transposition of the Great Arteries

- Anatomy of unrepaired Transposition of the Great Arteries
- Coronary anatomy in Transposition of the Great Arteries
- Anatomy of the atrial switch (Mustard/ Senning), arterial switch and Rastelli operations
- Optimal imaging techniques
- Assessment of physiological consequences
- Associated lesions
- Pre-intervention (surgical/ interventional cardiology) assessment
- Assessment of treatment complications

3/ Pulmonary Atresia VSD and MAPCAs

- Anatomy of repaired and unrepaired Pulmonary Atresia VSD and MAPCAs
- Optimal imaging techniques
- Assessment of physiological consequences
- Associated lesions
- Pre-intervention (surgical/ interventional cardiology) assessment
- Assessment of treatment complications

4/ Pulmonary Atresia Intact Ventricular Septum

- Anatomy of repaired and unrepaired Pulmonary Atresia Intact Ventricular Septum
- Optimal imaging techniques
- Assessment of physiological consequences
- Associated lesions
- Pre-intervention (surgical/ interventional cardiology) assessment
- Assessment of treatment complications

5/ Double Outlet Right Ventricle

- Anatomy of repaired and unrepaired Double Outlet Right Ventricle
- Optimal imaging techniques
- Assessment of physiological consequences
- Associated lesions
- Pre-intervention (surgical/ interventional cardiology) assessment
- Assessment of treatment complications

6/ Truncus Arteriosus

- Anatomy of repaired and unrepaired Truncus Arteriosus
- Optimal imaging techniques
- Assessment of physiological consequences
- Associated lesions
- Pre-intervention (surgical/ interventional cardiology) assessment

- Assessment of treatment complications

7/ Congenitally Corrected Transposition of the Great Arteries

- Anatomy of unrepaired Congenitally Corrected Transposition of the Great Arteries
- Anatomy of the double switch operation
- Optimal imaging techniques
- Assessment of physiological consequences
- Associated lesions
- Pre-intervention (surgical/ interventional cardiology) assessment
- Assessment of treatment complications

8/ Total Anomalous Pulmonary Venous Drainage

- Anatomy of repaired and unrepaired TAPVD
- Optimal imaging techniques
- Variants - Supracardiac; Cardiac; Infracardiac
- Assessment of physiological consequences
- Associated lesions
- Assessment of treatment complications

2.4. Complex Congenital Heart Disease

1/ Atrial isomerism

- Anatomy of atrial isomerism
- Appearance of different interventional and surgical palliations
- Optimal imaging techniques
- Assessment of physiological consequences

- Associated lesions
- Pre-intervention (surgical/ interventional cardiology) assessment
- Assessment of treatment complications

2/ Univentricular heart

- Anatomy of the univentricular heart
- Appearance of different interventional and surgical palliations
- Optimal imaging techniques
- Assessment of physiological consequences
- Associated lesions
- Pre-intervention (surgical/ interventional cardiology) assessment
- Assessment of treatment complications

3/ Double Inlet Ventricle

- Anatomy of the double inlet ventricle
- Appearance of different interventional and surgical palliations
- Optimal imaging techniques
- Assessment of physiological consequences
- Associated lesions
- Pre-intervention (surgical/ interventional cardiology) assessment
- Assessment of treatment complications

4/ Cavopulmonary and Fontan Circulations

- Anatomy of the different palliations performed

- Appearance of different interventional and surgical palliations
- Optimal imaging techniques
- Assessment of physiological consequences
- Pre-intervention (surgical/ interventional cardiology) assessment
- Assessment of treatment complications

2.5. Left-sided obstructive lesions

(see also aortic valve disease)

1/ Coarctation

- Anatomy of unrepaired and repaired coarctation of the aorta
- Optimal imaging techniques
- Assessment of physiological consequences
- Associated lesions
- Pre-intervention (surgical/ interventional cardiology) assessment
- Assessment of treatment complications

2/ Aortic Interruption

- Anatomy of unrepaired and repaired interruption of the aorta including classification
- Optimal imaging techniques
- Assessment of physiological consequences
- Associated lesions
- Pre-intervention (surgical/ interventional cardiology) assessment
- Assessment of treatment complications

3/ Supra-valvar aortic disease

- Anatomy of unrepaired and repaired supra-valvar aortic stenosis
- Optimal imaging techniques
- Assessment of physiological consequences
- Associated lesions
- Pre-intervention (surgical/ interventional cardiology) assessment
- Assessment of treatment complications

4/ Sub-valvar LVOT

- Anatomy of unrepaired and repaired sub-valvar LVOT
- Optimal imaging techniques
- Assessment of physiological consequences
- Associated lesions
- Pre-intervention (surgical/ interventional cardiology) assessment
- Assessment of treatment complications

2.6. Right-sided obstructive lesions

(see also pulmonary valve disease)

1/ Supra-valvar pulmonary and branch pulmonary artery stenosis; Williams; Alagille

- Anatomy of unrepaired and repaired branch PA stenosis
- Syndromes associated with pulmonary artery stenosis - Williams and Alagille
- Optimal imaging techniques
- Assessment of physiological consequences

- Associated lesions
- Pre-intervention (surgical/ interventional cardiology) assessment
- Assessment of treatment complications

2/ Sub-valvar - double chambered right ventricle

- Anatomy of sub-valvar stenosis and the double chambered RV
- Optimal imaging techniques
- Assessment of physiological consequences

3/ Pulmonary vein stenosis

- Causes of pulmonary vein stenosis
- CMR appearances of pulmonary vein stenosis
- Imaging appearances
- Optimal imaging techniques
- Physiological consequences

2.7. Coronary artery anomalies

1/ Anatomy of coronary artery variants

2/ Optimal imaging techniques

3/ Assessment of intramural course

4/ Associated lesions

5/ Pre-intervention (surgical/ interventional cardiology) assessment

6/ Assessment of treatment complications

2.8. Miscellaneous congenital lesions

1/ Cor triatriatum sinister and dexter

- Anatomy of unrepaired and repaired for triatriatum sinister and dexter (left-sided and right-sided)
- Optimal imaging techniques
- Assessment of physiological consequences
- Associated lesions
- Pre-intervention (surgical/ interventional cardiology) assessment
- Assessment of treatment complications

2/ Uhl's anomaly

- Anatomical features of Uhl's anomaly
- Physiological consequences
- Optimal imaging techniques

3. VASCULAR

1/ Aortopathy - Marfan; Bicuspid aortopathy; Loeys-Dietz; Ehlers Danlos *(see also congenital valve disease)*

- Optimal imaging techniques
- Assessment of aortic dimensions
- Pre-intervention (surgical) assessment
- Post-operative appearances including treatment complications
- Appearance of aortic dissection; intramural heamatoma; penetrating aortic ulcer
- Classification of aortic dissection
- Differentiation of true aneurysm and pseudo-aneurysm

2/ Vascular rings and pulmonary artery slings

- Anatomy of unrepaired and repaired vascular rings and pulmonary artery slings
- Optimal imaging techniques
- Local complications - tracheal and bronchial compression; oesophageal compression
- Associated lesions
- Assessment of treatment complications

3/ Pulmonary Hypertension

- Optimal imaging techniques
- Assessment of physiology
- Associated lesions

4. MYOCARDIAL DISEASE

1/ Dilated Cardiomyopathy

- Differential diagnosis of heart failure of unknown origin
- Optimal imaging techniques
- Late gadolinium enhancement patterns and prognostic importance

2/ Hypertrophic Cardiomyopathy

- Differential diagnosis of hypertrophic left and right ventricles
- Optimal imaging techniques
- Late gadolinium enhancement patterns and prognostic importance
- Physiological consequences of hypertrophic cardiomyopathy
- Complications of hypertrophy: outflow tract obstruction; mitral regurgitation
- Prognostic importance of CMR, late enhancement

3/ Arrhythmogenic Right Ventricular Cardiomyopathy

- Role of CMR in diagnosis of ARVC

- Optimal imaging techniques
- Differential diagnosis of right ventricle dilation
- Left ventricular involvement
- Optimal imaging techniques during arrhythmia

4/ Non-compaction Cardiomyopathy

- Diagnostic criteria for non-compaction (including differences between echo and CMR)
- Late gadolinium enhancement in non-compaction

5/ Restrictive Cardiomyopathy

- Differential diagnosis of restrictive cardiomyopathy
- Optimal imaging techniques
- Physiological consequences of restrictive cardiomyopathy
- Late gadolinium enhancement pattern
- Differentiating restrictive cardiomyopathy from constrictive pericardial disease

6/ Myocarditis

- CMR criteria for the diagnosis of myocarditis (Lake Louise criteria)
- Optimal imaging techniques
- Late gadolinium enhancement patterns

7/ Cardiomyopathy secondary to systemic disease

- Muscular dystrophy
- Endomyocardial fibrosis

- Sarcoidosis
- Amyloidosis
- Iron overload - T2* imaging

5. Congenital Valve Disease

1/ General Principles of valve disease

- Anatomy of the tricuspid, pulmonary, mitral and aortic valves
- Assessment of valve stenosis
- Assessment of valve regurgitation
- Quantification of valve regurgitation in the presence of multiple regurgitant valves
- Physiological consequences of valve disease
- Optimal imaging techniques
- Associated lesions

2/ Congenital aortic stenosis (see also left-sided obstructive lesions)

- Anatomy of aortic valve abnormalities
- Assessment of severity of stenosis and regurgitation
- Associated lesions - other left-sided obstructive lesions; endocardial fibroelastosis
- Assessment of the patient following the Ross operation
- Physiological consequences
- Optimal imaging techniques

3/ Ebstein's anomaly of the tricuspid valve

- Anatomy of repaired and unrepaired Ebstein's anomaly
- Associated lesions

- Physiological consequences of Ebstein's anomaly
- Pre-surgical assessment

4/ Bicuspid aortic valve disease (see also aortopathy)

- Anatomical variants of bicuspid aortic valve
- Associated lesions
- Aortopathy

5/ Prosthetic valve assessment

- Appearance of biological and mechanical prosthetic valves
- Assessment of prosthetic valve function
- Assessment of complications from valve implantation
- Physiological consequences of valve disease
- Optimal imaging techniques
- Pre-intervention assessment for percutaneous valve implantation (PPVI, TAVI)

6. ACQUIRED CARDIOVASCULAR DISEASE OF CHILDHOOD

1/ Kawasaki Disease

- Anatomical appearances
- Assessment of complications
- Optimal imaging techniques

2/ Takayasu Arteritis

- Anatomical appearances
- Diagnostic criteria

- Assessment of complications
- Optimal imaging techniques
- Post-operative appearances including treatment complications

3/ Infective endocarditis

- Anatomical appearances
- Assessment of complications - valve dysfunction; abscess; fistulae; perforation
- Optimal imaging techniques

4/ Rheumatic Fever

- Anatomical appearances
- Assessment of complications - valve dysfunction; endocarditis
- Optimal imaging techniques

5/ Intravascular thrombosis

- Anatomical appearances
- Assessment of complications - valve dysfunction; endocarditis
- Optimal imaging techniques

7. ISCHAEMIC HEART DISEASE

1/ Normal coronary anatomy, and anatomy of anomalous coronary arteries

2/ Features of intramural coronary course

3/ Optimal imaging techniques for anatomical and functional assessment

4/ Late gadolinium enhancement patterns

5/ Assessment of ventricular remodelling and physiological consequences

6/ Assessment of viability

7/ Ischaemia assessment using - adenosine; regadenoson; dobutamine

8/ First pass perfusion imaging during rest and stress

9/ Regional and global functional assessment during stress

10/ Assessment of complications of myocardial infarction - thrombus; aneurysm; VSD; valvar regurgitation

11/ Kawasaki disease

12/ Takayasu Arteritis

13/ Complications as a result of coronary translocation - arterial switch operation in TGA; ALCAPA

8. PERICARDIAL DISEASE

1/ Normal anatomy of the pericardium

2/ Optimal imaging techniques

3/ Aetiology of pericardial disease

4/ Physiology of the normal pericardium and the consequences of pericardial disease

5/ Congenital absence of the pericardium

6/ Pericarditis acute and chronic

7/ Pericardial effusions and tamponade

8/ Constrictive pericarditis and its differentiation from restrictive cardiomyopathy

9/ Pericardial cysts

10/ Pericardial tumours (benign and malignant)

9. CARDIAC TUMOURS (WITH PARTICULAR EMPHASIS ON TUMOURS IN CHILDHOOD)

1/ Epidemiology, pathophysiology and clinical presentation of cardiovascular tumours

2/ CMR appearances and typical locations of tumours

3/ Late gadolinium enhancement patterns

4/ Physiological consequences

5/ Features suggestive of malignancy

6/ Optimal imaging techniques

7/ Common tumours of childhood - Fibroma; Rhabdomyoma; Teratoma

8/ Malignant tumours - primary, including sarcoma and lymphoma, and secondary metastatic

9/ Haemangioma; Lipoma; Fibroelastoma; Myxoma

10/ Thrombus

11/ Paraganglioma

10. INCIDENTAL FINDINGS

1/ Recognition of common incidental findings within the neck thorax and abdomen

2/ A detailed knowledge of extra-cardiovascular pathology is not required, but a recognition that something is abnormal is important

- Lymphadenopathy
- Thyroid nodules
- Bronchial disease (narrowing - intrinsic and external compression; bronchiectasis)
- Lung (airspace consolidation; nodule; tumour)
- Pleura (effusions; thickening)
- Mediastinum (lymphadenopathy)
- Oesophagus (dilation; hiatus hernia; duplication cysts)
- Thymus
- Musculoskeletal (fracture; tumour)
- Breast (cyst; tumour)
- Liver (cyst; haemangioma; tumour; cirrhosis)
- Gallbladder (gallstones)

- Spleen (splenomegaly)
- Pancreas (cyst; tumour)
- Kidney (cyst; haemagioma; hydronephrosis)
- Adrenal (tumour)
- Ascites